

# Task 2 DER-CAM work supporting the TMO and DER-CAM integration

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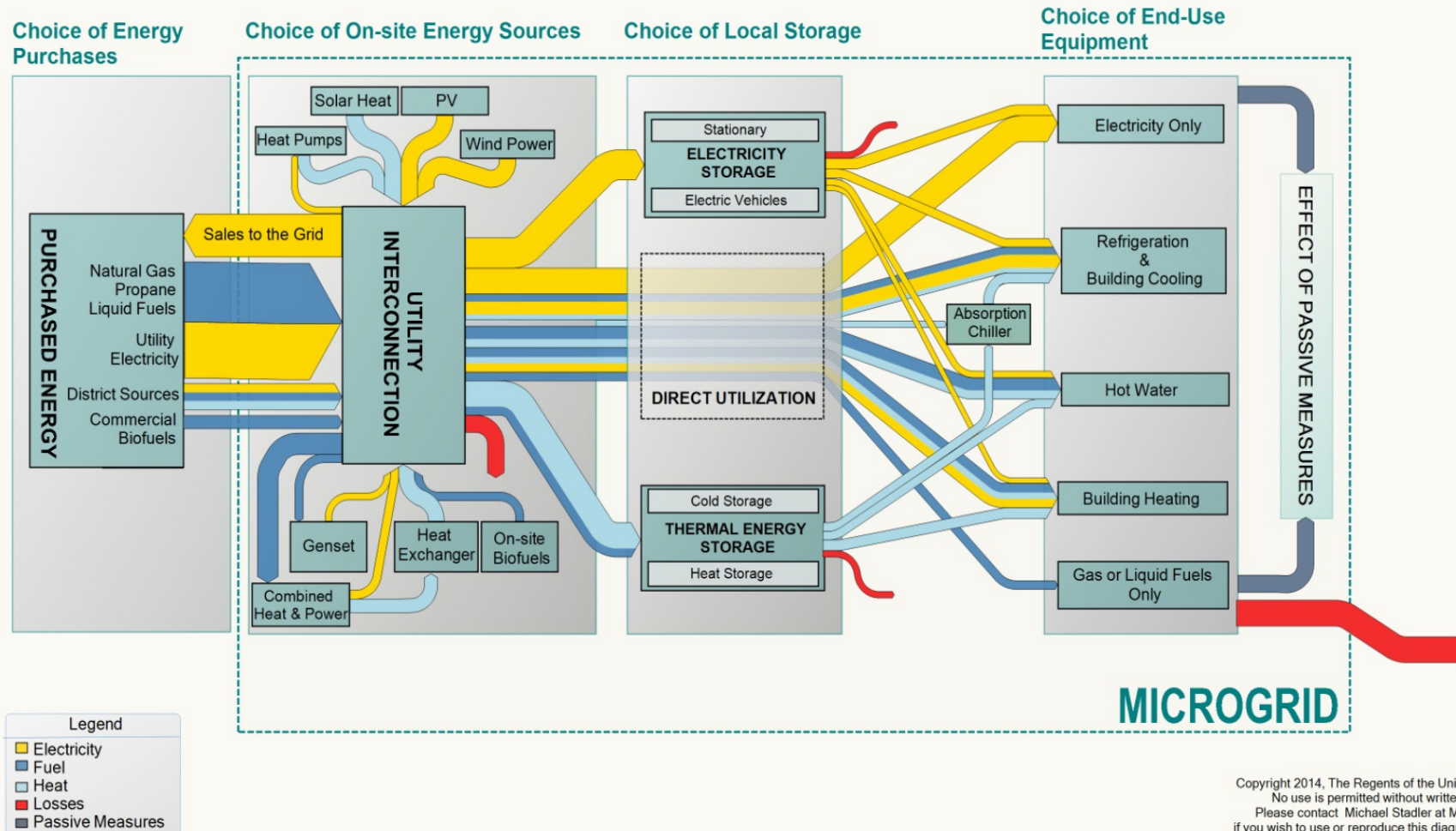
OE meeting  
23 Apr 2014  
Michael Stadler

Team: C. Marnay, C. Milan, D. Baldassari,  
G. Cardoso, J. Eto, J. Tjaeder,  
M. Stadler, N. DeForest, S. Wang,  
T. Brandt, W. Feng

mstadler@lbl.gov  
building-microgrid.lbl.gov



# Global Model Concept for Microgrids



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# What is DER-CAM?

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## Distributed Energy Resources Customer Adoption Model (DER-CAM)

- is a Mixed Integer Linear Program (MILP), written in the General Algebraic Modeling System (GAMS®)
- minimizes annual energy costs, CO<sub>2</sub> emissions, or multiple objectives of providing services on the building level (typically microgrids with 100-2000 kW peak)
- produces technology neutral pure optimal results
- has been developed for more than 12 years by Berkeley Lab and collaborations in Australia, Europe, Asia, and the US
- commercialization (*web clients*) and real-time optimization
- more than 400 DER-CAM *web clients* to date (web interface)
- currently 17 different versions with different capabilities

# DER-CAM Users

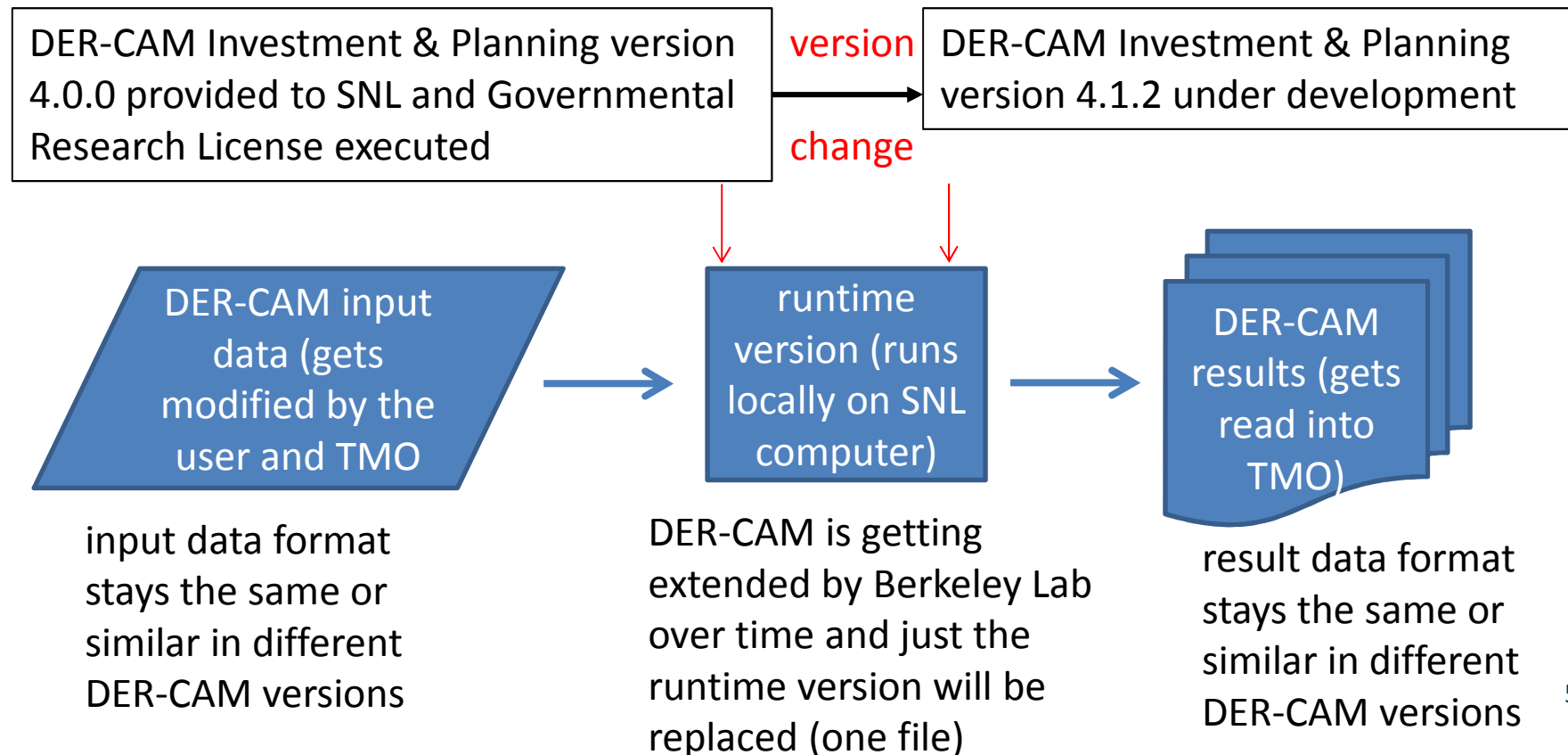


# DER-CAM TMO Integration



## DER-CAM delivers grid-connected results for task 2:

- ✓ cost reduction
- ✓ CO<sub>2</sub> reduction



# Work Supporting Task 2

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- ✓ non-linear efficiency curves
  - ☺ stepwise approximation
  - ☹ journal paper to be submitted in May
- ✓ solar database, online help, and tutorial movie for WebOpt
- ✓ optimization while islanded/critical loads, smart inverter capabilities
  - ☺ load prioritization
  - ☺ outage events
  - ☹ test phase
  - ☹ journal paper in early preparation stages
  - ☹ reactive / active power control



# Work Supporting Task 2

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- ✓ multi-year optimization (up to 20 years) and re-investments
  - 😊 load variability
  - 😊 tariff changes
  - 😊 technology degradation (PV and Batteries)
  - 😐 test phase
  - 😐 journal paper in early preparation stages
- ✓ improved modeling of thermodynamics in buildings (electrochromatic windows)
- ✓ support of wind power
  - 😐 test phase
- ✓ unbundle network transmission/distribution tariffs



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## Non-Linear Electric and Heating Efficiencies for CHP and DG



# Non-Linear Efficiency Curves – New Modelling of CHP/DG

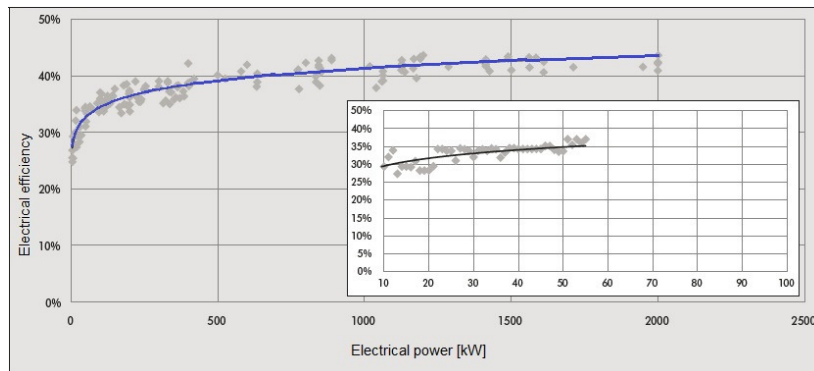


constant efficiencies problematic since

a) installed capacity  
affects maximal efficiency

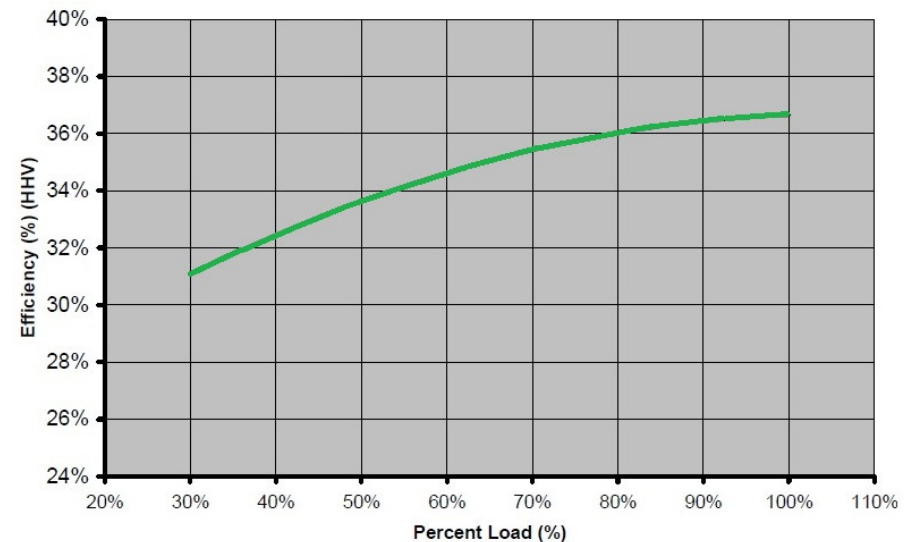
b) part load performance  
affects actual efficiency

Electrical efficiencies for natural gas powered CHPs  
based on installed capacities  $P_{inst}$



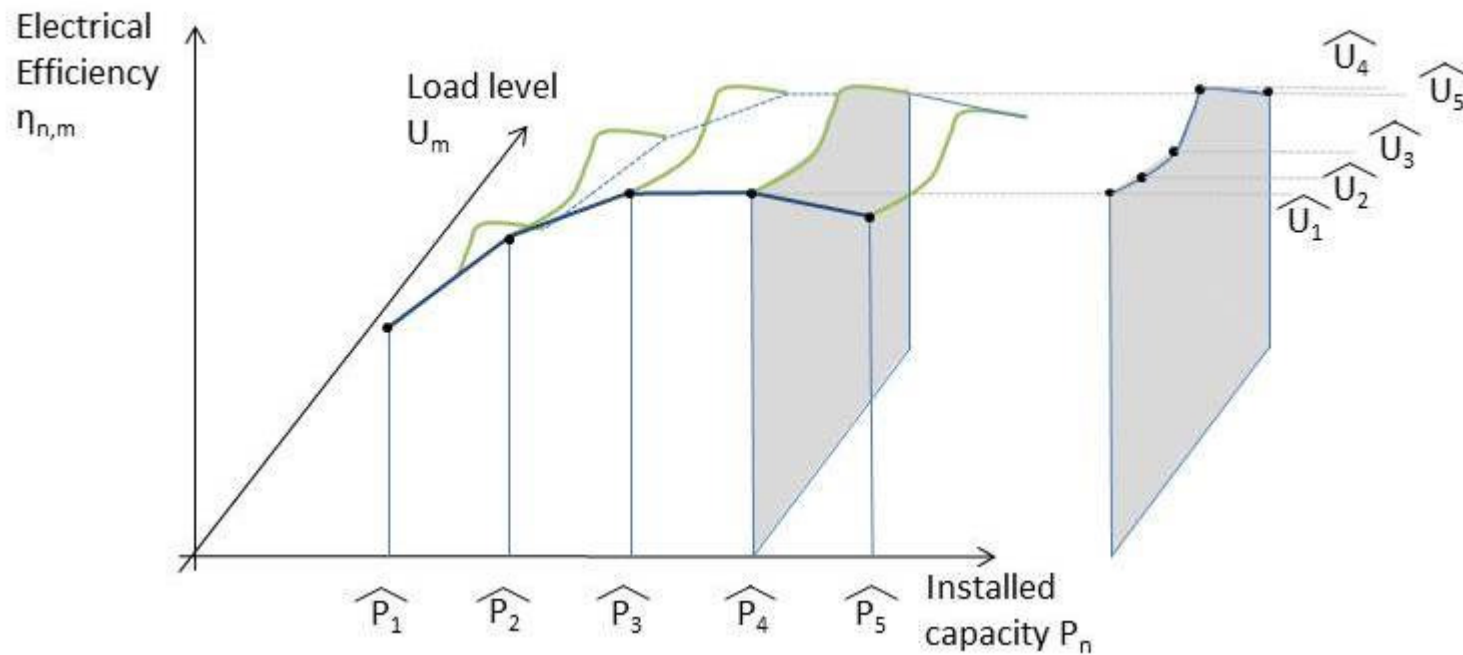
Source: ASUE, 2011

Typical efficiencies for natural gas powered CHPs  
based on load levels  $U$



Source: EEA, 2008

# Stepwise Linear Optimization



$$\eta_t = f_t(P_{inst}, U_t) = \sum_{i=1}^n \sum_{j=1}^m (f(\widehat{P}_i, \widehat{U}_{i,j}) * x_{t,i,j})$$

⇒ consecutive variables

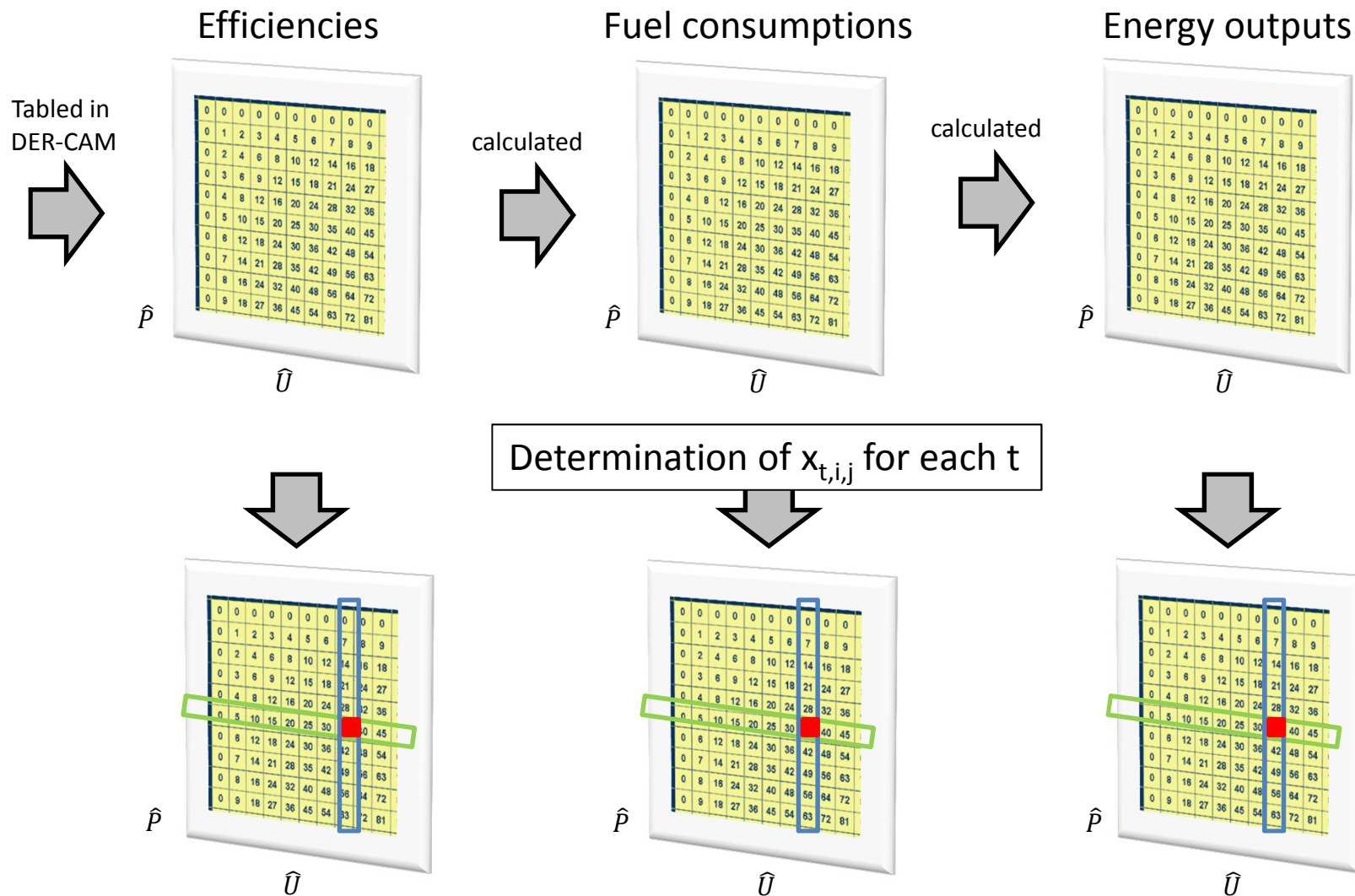
⇒ not more than two adjacent  $\neq 0$

⇒ binary variables avoided

$$\sum_{i=1}^n \sum_{j=1}^m x_{t,i,j} = 1$$

$$x_{t,i,j} \geq 0$$

# Implementation in DER-CAM



# Implementation in DER-CAM



Hospital building in San Francisco  
changes of SOS version compared to fixed efficiency  
CO<sub>2</sub> minimization

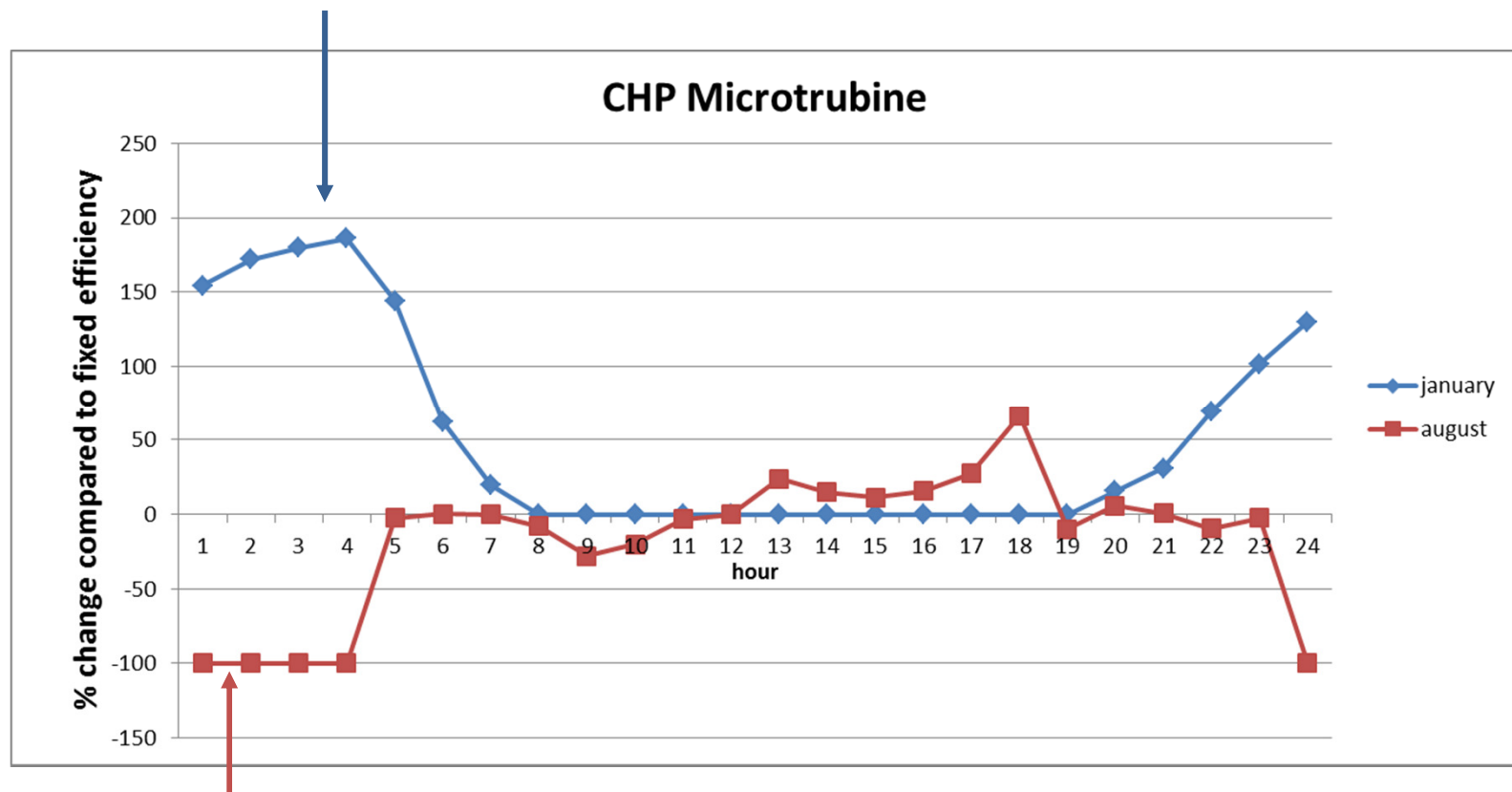
changes compared to the fixed efficiency version	
total costs [%]	1
total CO <sub>2</sub> Emissions [%]	-3
CHP installation [%]	0
PV installation [%]	-100
solar thermal installation [%]	205
heat storage installation [%]	#inf!
elec. generated [%]	1
Elec. purchase [%]	6
NG <u>not</u> used in CHP [%]	-59
NG used in CHP[%]	6

better  
modelling of  
CHP efficiency  
curves impacts  
mostly PV,  
solar thermal,  
and heat  
storage

# Changes in Operational Levels



*limited heat storage and  
solar thermal in winter*



*due to heat storage and solar  
thermal in summer*



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## Solar Database, Online Help, and Tutorial Movie for WebOpt

# Solar Database for WebOpt



Distributed Energy Resources (DER) Web Optimization Service (WebOpt)

WebOpt File WebOpt Help

Run optimization

GO

Overview/Optimization Settings Load Profiles Utility Tariffs Technologies Demand Response **Solar Radiation** Marginal CO2 Macrogrid Results

This Tab shows the detailed solar radiation data for the selected location.  
Please note that solar radiation is shown for a fixed PV or solar thermal panel tilt that is exactly the latitude of the selected location.

? Sacramento, CA, USA Open Database ?

kW/m2	hour 1	hour 2	hour 3	hour 4	hour 5	hour 6	hour 7	hour 8
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16
April	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.24
May	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.27
June	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.28
July	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.25
August	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.24
September	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
October	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Discard all changes

Solar Profile Database

Database

US

TM2

Alabama

BIRMINGHAM MUNICIPAL AP.xls

MORRIS REGIONAL AP.xls

MONTGOMERY DANNELLY FIELD

Alaska

Arizona

Arkansas

California

Colorado

Connecticut

Delaware

Florida

Georgia

Please select a dataset (TM2 or TMY3) from the database (click on the folder icon), then state, and location. Finally, "load" the data. All data reflects a tilt equal to the location's latitude, facing south.

Load Data

Cancel

kW/m2

1

0.8

0.6

0.4

0.2

0

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16



# WebOpt User Manual



Distributed Energy Resources (DER) Web Optimization Service (WebOpt)

WebOpt File WebOpt Help

Overview/Optimization Settings Load Profiles Utility Tariffs Technologies Demand Response Solar Radiation Marginal CO2 Macrogrid Results

Run optimization

GO

Discard all changes

BERKELEY LAB

U.S. DEPARTMENT OF ENERGY

**WebOpt User Manual**

DER Web Optimization Service (WebOpt):  
a project partly financed by  
the U.S. Department of Energy

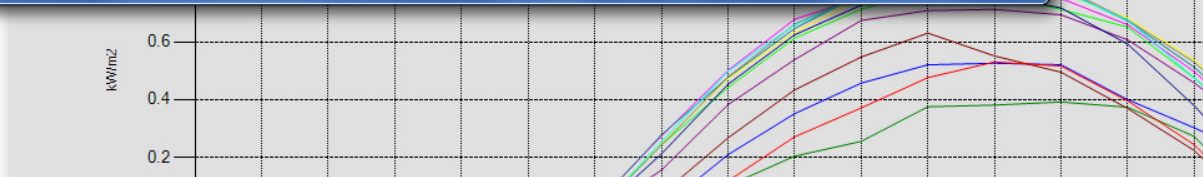
for Version 2.5.1.26  
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Lawrence Berkeley National Laboratory (LBNL)

Search Manual for: Search Next OK

Selected location.

hour 15	hour 16	hour
0.37	0.27	C
0.40	0.30	C
0.61	0.46	C
0.65	0.47	C
0.66	0.50	C
0.67	0.51	C
0.68	0.54	C
0.68	0.53	C
0.68	0.47	C
0.59	0.38	C
0.37	0.22	C
0.40	0.24	C

kWh/m2

A line graph showing kWh/m2 on the y-axis (ranging from 0.2 to 0.6) against time on the x-axis. Multiple colored lines represent different data series, showing a general upward trend followed by a decline.

# WebOpt Tutorial

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[http://building-microgrid.lbl.gov/sites/all/files/projects/WebOpt\\_Take2.mp4](http://building-microgrid.lbl.gov/sites/all/files/projects/WebOpt_Take2.mp4)

WebOpt 2.5.1.26 will be released soon after final testing



# Multi-Year Optimization

# Multi-Year Optimization

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## Challenges:

- microgrids are often modular
- investment decisions over the years are influenced by trends both in energy demand and technology costs
- technology degradation over time must be considered
- find optimal investment and re-investment years over the multi-year period

# Multi-Year Optimization

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## Improvements in multi-year optimization:

- load variability
- fuel cost changes
- technology degradation
- changing tariffs
- changing taxes
- changing weather data

# Multi-Year Optimization



**Utility purchases** and **general expenses** are calculated as **present values**.

$$I(y) = \frac{I}{(1+i)^{y-1}}$$

$$EAC(y) = \frac{I}{(1+i)^{y-1}} * \frac{i}{1 - \frac{1}{(1+i)^L}}$$

$y$  year

$L$  lifetime (years)

$i$  interest rate (dimensionless)

$I$  value of capital cost on year 1 (\$)

$I(y)$  capital cost on year  $y$  (\$)

$EAC(y)$  equivalent annual cost on year  $y$  (\$)

**Investments** are calculated as **present values** and then spread over the technology lifetime as **equivalent annual costs**.

Year (y)	1	2	3	4	5	6	7	8	9	10
Upfront capital cost I(n) (in \$)	1000					1000				
Actualized value of I (in \$)	1000					863				
Equivalent annual cost EAC (in \$)	218	218	218	218	218	188	188	188	188	188
Sum of the EAC (in \$)	1092					942				

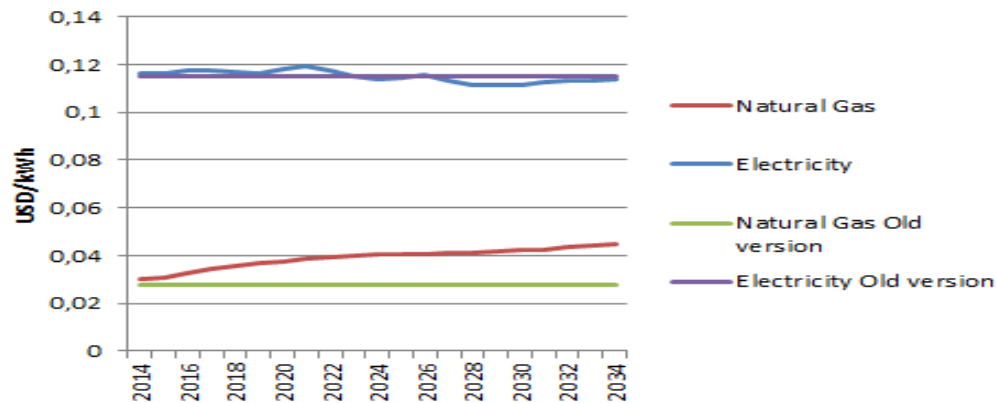
**This approach is under revision**

# Multi-Year Optimization



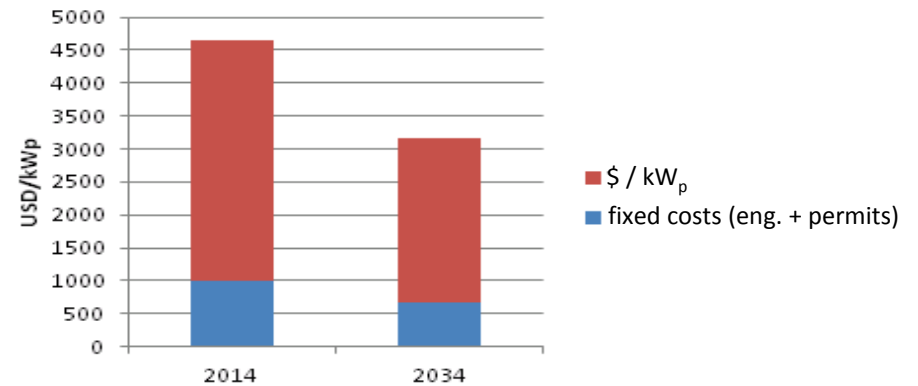
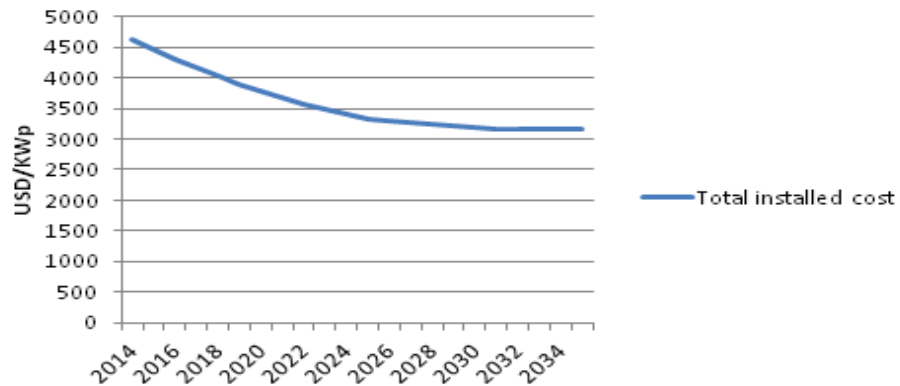
## Application: Office building in San Francisco

### Fuel Costs



[Annual Energy Outlook, EiA 2013]

### PV Capital Cost forecast





# Multi-Year Optimization



## Investment plan

Installed Technologies	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033							
0% PV Degradation																											
PV 0% degradation						Still running...																					
Discrete Technologies																											
> CHP																											
Batteries																											
0.5% PV Degradation																											
Installed Capacity, PV 0.5% degradation								(497.13kW) 0.50% degradation													(467.3kW)						
Discrete Technologies	(500kW)																										
> CHP	(250kW)																										
Batteries	No Adaptation																										
0.75% PV Degradation																											
Installed Capacity, PV 0.75% degradation													(498.45kW) 0.75% degradation													(464.81kW)	
Discrete Technologies	(500kW)																										
> CHP	(250kW)																										
Batteries	No Adaptation																										
1% PV Degradation																											
Installed Capacity, PV 1% degradation						Still running...																					
Discrete Technologies																											
> CHP																											
Batteries																											
Old Run-set																											
Installed Technologies	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033							
PV							No Ad.										No Ad.										
Discrete Technologies							250kW										800kW										
> CHP							250kW										800kW										
Batteries							145kWh										No Ad.										



# Improved Modeling of Thermodynamics in Buildings: Electrochromatic Windows

# Shading



- Electrochromatic (EC) windows are a type of shading system. EC provide different levels of shading with a small electricity consumption required for the switching process ( $0.5\text{Wh/m}^2$ , 5V), which can be used to control building cooling loads.
- Trade-off: Increased levels of shading reduce cooling loads, but increase lighting loads.

→ **Optimization problem**

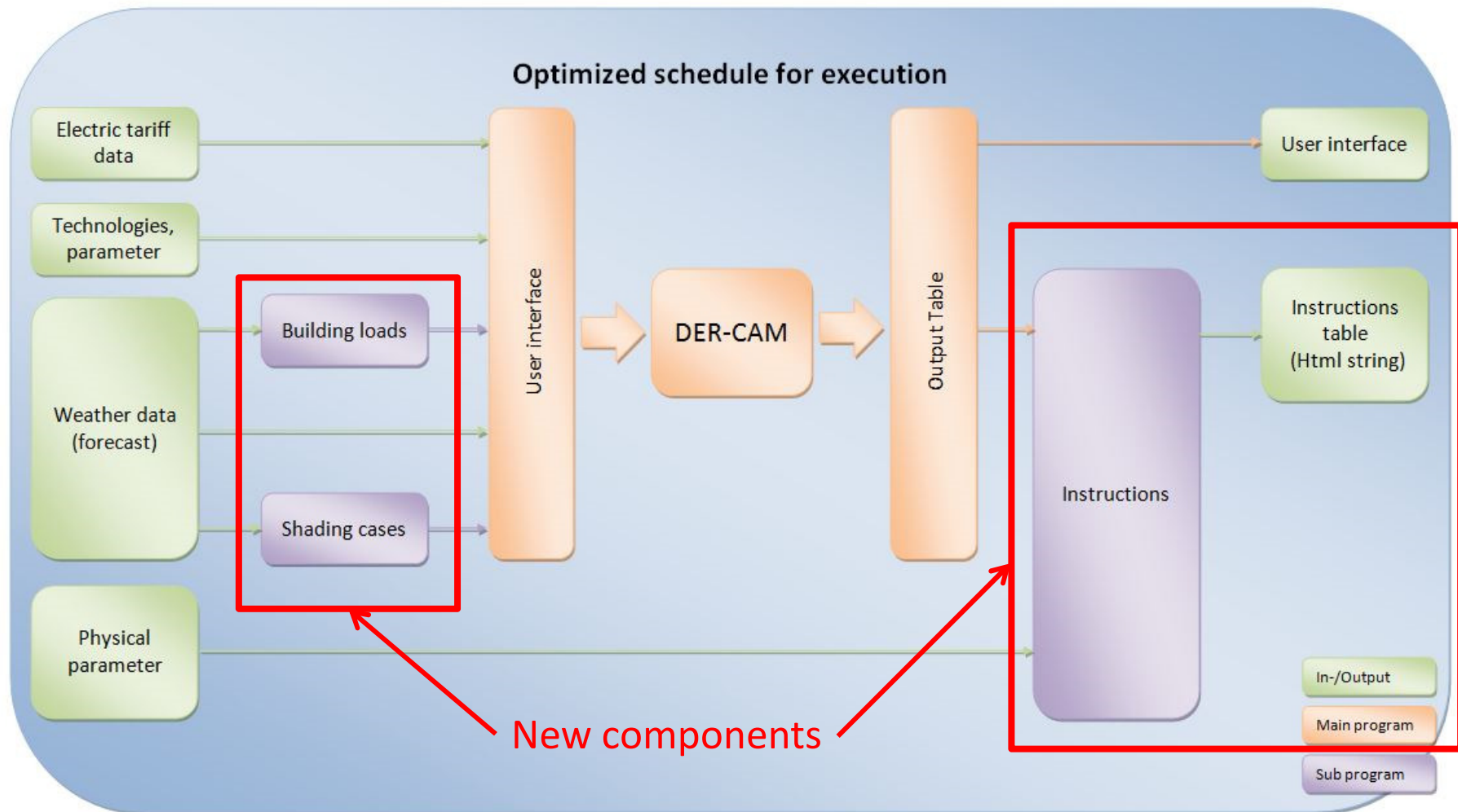


# Shading



- DER-CAM will support variable shading (EC windows, shutters) in the Operations version
- user is required to input load changes (electrical and cooling) for different shading levels
- requires pre-processing of environmental conditions for shading levels (lookup table) and building loads (E+)
- DER-CAM finds optimal shading levels for each time step (down to 5 min)

# Shading



# Shading

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## Applications

- evaluate technical potential
- run optimization for possible buildings in China (China Energy Group at LBNL)

## Status

- most of programming completed



# Wind Power



# Wind Power

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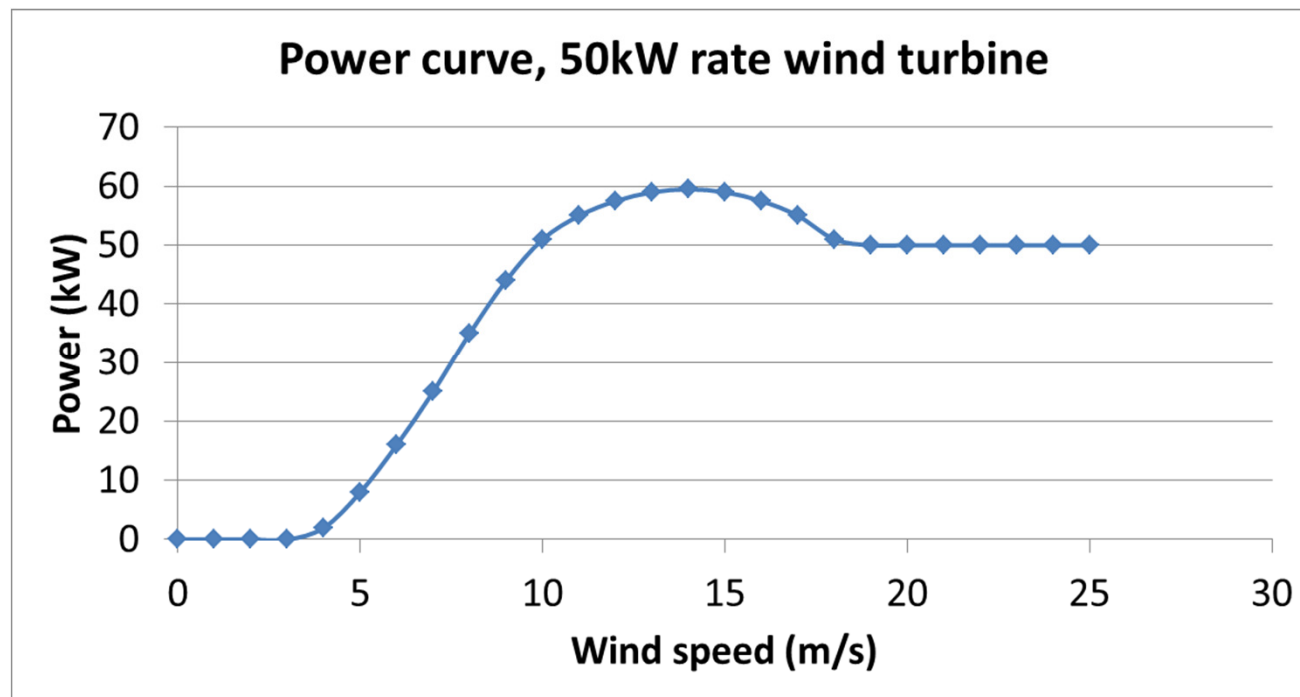


- DER-CAM now supports wind power in the Deterministic Investment & Planning version
- user is required to input wind speeds, power curve and cost coefficients
- the current time structure used in DER-CAM (36 typical days of hourly loads) requires pre-processing of wind data (*vs. 365 daily loads*)
- the spreadsheet pre-processing provides potential wind generation values, which are fed into DER-CAM
- DER-CAM finds the optimal number of wind turbines to be installed at study site.

# Wind Power: time consistency



- DER-CAM considers 3 (or 7) representative days per month, each described by 24h time steps
- non-linear power curves and cut-in / cut-out speeds lead to high impact of time discretization



# Wind Power: time consistency



	Wind	Power
Time	m/s	kW
00:10	2.14	0.00
00:20	2.53	0.00
00:30	3.06	0.13
00:40	3.59	1.18
00:50	3.99	1.97
01:00	4.17	3.04
	AVG	
	3.25	1.05

## Example

In this case, with data sampled from on-site measurements, the average wind speed is below the 3.5 m/s cut-in speed, and yet the energy output is not zero

# Wind Power: time consistency



- data format required by DER-CAM requires wind output to be processed after wind-power calculations

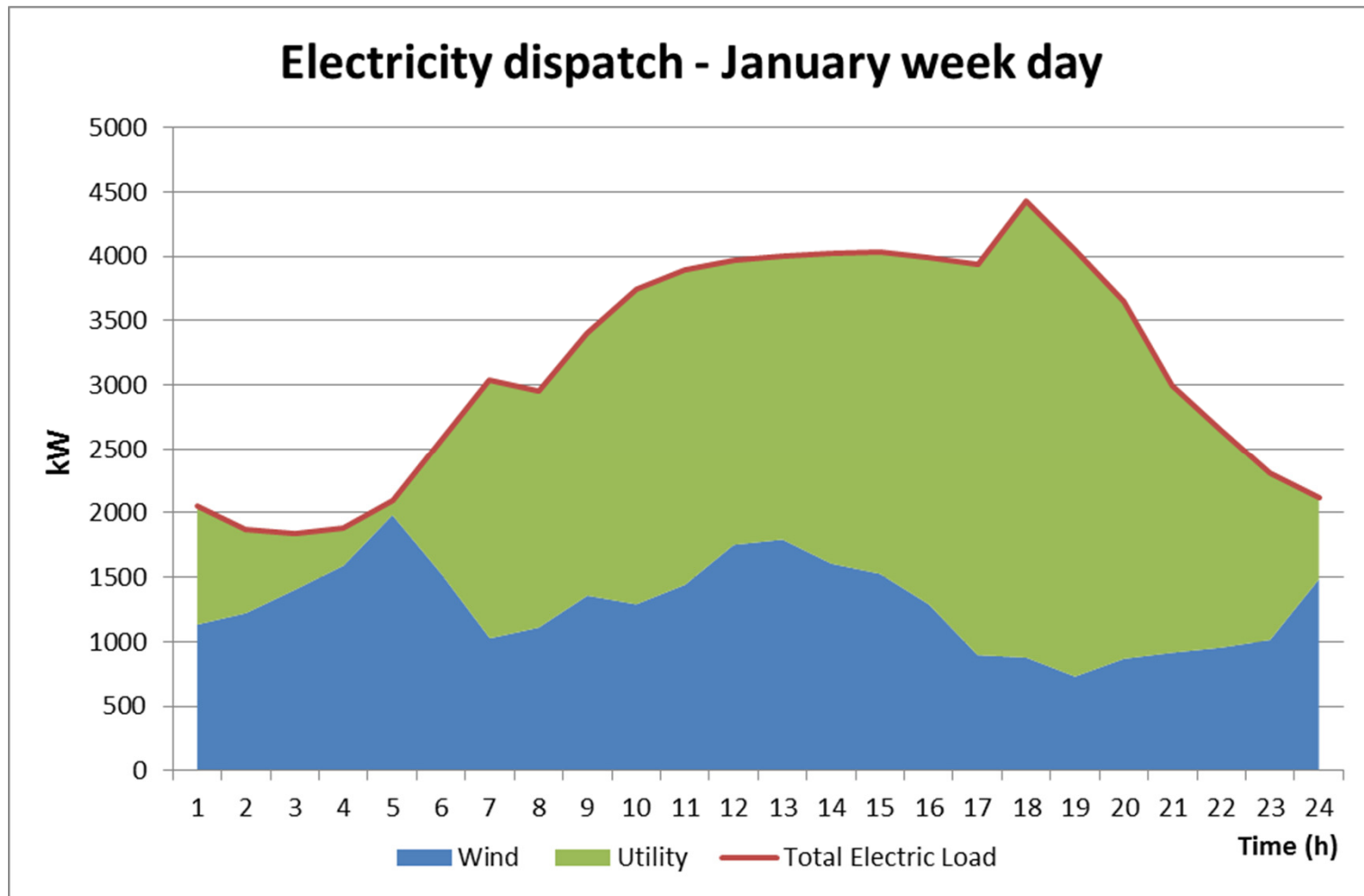
energy output: raw wind data → processing of wind / power calculations

month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	5.84	6.30	7.23	8.20	10.22	7.88	5.29	5.72	7.00	6.65	7.43	9.03	9.24	8.28	7.87	6.65	4.62	4.52	3.76	4.47	4.72	4.92	5.23	7.65
2	9.86	10.24	10.93	7.43	6.37	5.17	6.02	6.70	4.96	5.46	7.01	7.97	7.91	9.00	8.23	7.82	7.32	6.88	6.51	5.81	5.23	6.52	8.35	10.17
3	19.72	20.33	18.97	17.22	14.31	12.09	12.16	13.64	14.99	14.28	13.77	14.46	13.77	13.07	11.83	11.59	10.25	9.51	10.14	10.27	13.27	14.50	17.48	20.01
4	14.27	12.49	9.87	10.21	8.93	9.55	8.87	7.05	7.29	7.62	7.11	6.55	5.99	5.38	7.82	6.82	4.80	5.88	7.32	8.38	9.41	13.05	15.14	18.01
5	12.30	12.73	10.80	8.21	7.14	7.38	7.12	5.96	4.69	3.50	3.02	2.50	2.07	2.50	3.05	2.81	2.92	4.27	4.67	5.21	5.70	6.91	9.00	12.45
6	11.73	10.83	9.51	9.09	9.09	9.14	8.97	7.51	7.72	7.33	5.04	4.21	3.43	2.97	1.92	1.29	1.30	1.48	2.23	2.33	2.86	4.13	6.61	13.10
7	13.19	11.47	11.73	13.47	13.05	11.77	11.20	9.49	7.74	6.20	4.72	2.89	2.19	1.62	1.33	0.63	1.23	2.15	3.01	3.82	4.55	5.51	7.62	11.68
8	8.75	7.54	6.60	6.69	5.63	4.32	4.35	3.69	3.03	2.10	1.98	1.66	1.54	1.41	1.06	0.78	0.67	0.69	0.92	1.34	1.82	2.31	4.02	6.77
9	6.97	6.30	6.58	5.03	4.17	4.09	4.03	3.02	2.18	1.33	0.93	0.48	1.02	1.31	1.63	1.85	1.96	3.36	4.13	4.73	4.68	4.15	4.95	7.76
10	9.04	6.87	7.33	5.97	5.23	5.21	3.76	2.89	2.00	2.01	1.95	2.05	2.29	1.97	1.85	1.95	1.83	1.23	1.73	2.30	2.64	2.35	3.32	6.01
11	7.35	8.04	6.73	7.07	5.88	4.30	4.30	2.99	3.20	2.63	1.97	1.98	1.03	0.94	0.82	0.99	1.35	2.32	2.82	3.45	3.47	3.47	4.38	7.21
12	7.26	6.54	5.73	7.69	6.82	7.26	5.96	6.53	6.29	6.16	5.21	5.33	5.46	4.69	5.11	6.51	6.91	7.96	7.65	7.95	8.96	9.37	8.94	9.13

energy output: processing of raw wind data → wind / power calculations

month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1.6	1.6	2.2	2.2	3.0	1.5	1.0	0.6	0.8	1.0	1.3	1.5	1.8	1.7	1.4	0.9	0.0	0.0	0.0	0.0	0.2	0.3	1.1	1.8
2	9.4	7.2	5.3	1.6	0.8	0.0	0.1	0.3	0.0	0.0	0.3	0.6	0.6	1.2	1.1	1.0	0.8	0.8	1.0	1.4	1.8	2.8	3.9	7.7
3	15.2	17.4	16.2	12.8	9.8	6.7	6.7	8.4	9.7	9.8	8.1	7.8	7.2	7.4	6.2	5.0	1.9	1.8	3.9	5.4	8.0	9.6	12.6	15.1
4	11.8	9.4	7.1	6.2	4.9	5.4	3.6	1.8	1.8	1.5	0.9	0.5	0.6	0.5	1.2	0.7	0.4	1.2	1.9	3.2	4.7	8.5	11.0	15.5
5	10.1	10.8	7.8	5.3	3.5	2.7	2.2	1.7	1.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.9	1.5	2.2	4.8	8.9
6	8.8	7.8	7.2	6.5	5.3	5.2	5.5	3.8	2.6	1.9	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.6	4.6	10.2
7	11.6	9.4	8.9	11.0	10.6	8.9	7.8	6.4	4.9	3.0	1.8	0.8	0.5	0.0	0.0	0.0	0.0	0.2	0.8	1.2	1.6	2.3	4.9	9.9
8	6.1	5.5	4.5	4.1	1.9	1.3	1.1	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.5	3.0
9	3.5	2.2	1.6	0.5	0.1	0.2	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.5	1.3	3.9
10	5.6	2.9	1.9	1.2	0.8	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.7	2.2
11	1.8	2.0	1.1	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.4
12	4.2	2.2	1.0	0.6	0.2	0.4	0.4	0.9	0.4	0.1	0.0	0.0	0.0	0.0	0.1	0.4	0.7	0.9	0.4	0.7	1.5	2.7	3.6	4.6

# Wind Power



Test results for Large College building

# Wind Power

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## First results

- wind turbines are not cost-effective without subsidies or incentives
- wind power can provide a significant part of the total load
- unpredictability of wind speed requires coupling with energy storage
- the current representation of time in DER-CAM introduces significant limitations in wind power modeling
- possible need to increase time resolution and/or add higher number of representative days

# End

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Thank you!

Questions and comments are very welcome.